Design of UPQC with Minimization of DC Link voltage for the Improvement of Power Quality by Fuzzy Logic Controller

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***Abstract*— Devices such as power electronics converters, inject harmonic currents in the AC system and increase overall reactive power demanded by the equivalent loads are presents non-linear characteristics. Also, the number of sensitive loads that require ideal sinusoidal supply voltages for their proper operation has increased. In order to keep power quality under limits proposed by standards, it is necessary to include some sort of compensation. The aim of this paper is to present a unified power quality conditioner (UPQC) with minimization of DC Link voltage for the improvement of power quality by Fuzzy logic controller as compared with PI controller. By the proposed system is comprised of series and shunt Inverters which can compensate the sag, swell, unbalance voltage, Harmonics and reactive power. PI and fuzzy logic controllers are used to stabilize DC link voltage and balance the active power between shunt and series inverters for the enhancement of power quality.**

***Keywords*—unified power quality conditioner,fuzzy logic controller, powewr quality, dc link voltage**

I.Introduction

In recent years, the electrical power quality is a more and more discussed issue. The main problems are stationary and transient distortions in the line voltage such as harmonics, flicker, swells and sags and voltage asymmetries. With the significant development of power electronics technology, especially static power converters [1] (well known as non-linear loads), voltage harmonics resulting from current harmonics produced by the non-linear loads have become a serious problem. Paradoxically, static power converters , the source of most of the perturbations, could also be used efficiently as active power filters in order to cancel or mitigate the above mentioned power quality problems as well as other power systems troubles such as damping of voltage oscillations .

The basic principle of active power filtering is to synthesize and apply a certain current or voltage waveform at a specified point of a distribution network. Active filters are fundamentally static power converters designed to synthesize a current or voltage source; alternatively, magnitude and phase. they can be made to emulate specified impedances, both in magnitude and phase[2]. The common application of active filtering combines the tasks of harmonic filtering and power factor compensation. Apart from this complex comprehensive active filters have been proposed in the context of total power quality management concept. Some of the power filtering applications is categorized as custom power devices. The controlling structure, back to back inverters might have different operations in compensation. For example, they can operate as shunt and series active filters to simultaneously compensate the load current, harmonics and voltage oscillations. This is called unified power quality conditioner; its principle structure is given in figure. [1-3].

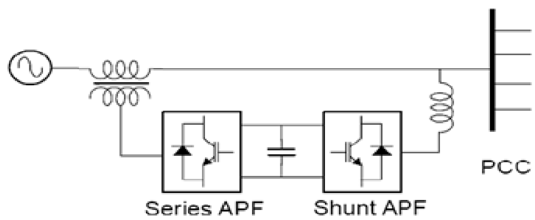

Figure 1. Basic structure of UPQC

UPQC controller provides the compensation voltage (v^*_f) through the UPQC series inverter and provides conditioning current (i^*_f) through the generated to be applied to series voltage source inverter switches.

This paper proposes a control technique for UPQCs based on a Fuzzy logic controller approach. The proposed method operates for allowing the selective compensation of voltage and current harmonics with fast dynamical responses. Moreover, the impact of dips and over-voltages can be attenuated by applying the proposed controller by minimizing the DC link voltage distortions.

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II.FUNCTIONAL STRUCTURE OF UPQC

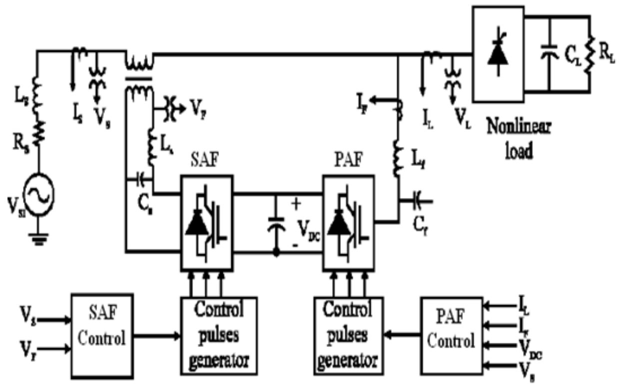

Figure 2. Functional structure of UPQC

The basic functionalities of a UPQC controller are depicted in figure 2. The voltage compensation (v*f) and current injection (i*f) reference signals, required for compensation purposes, are evaluated from the instantaneous measurements of the source voltage (VS), the dc-bus voltage (Vdc) and the load current (IL). These reference signals are compared to the measured feedback signals v1 and i2 and applied to the decoupled voltage and current controllers, which ensure that the compensation signals correspond to the reference ones.The gate signals of the power converters are obtained by applying pulse width modulators to the controlleroutputs. The power converters switch at high frequency generating a PWM output voltage waveform which must be low-pass filtered (in case of series APF and the shunt APF). Different approaches have been proposed for current control of grid-connected voltage source converters. Hysteresis controllers are implemented by means of simple analog circuits but, as drawback, the spectrum of the output current is not localized which complicates the output filter design [10]. PI controllers have been widely applied but, due to their finite gain at the fundamental grid frequency, they can introduce steady state errors. This can be solved by means of Fuzzy logic controller has been also proposed as current controllers.

This study is consisted of three main parts: selection of controlling method, design of Active filters, and design of Fuzzy logic controller. The design of Active filters section has three subsections: shunt active filter control, DC link control and series active filter control. Theses parts have discussed and finally the simulation results have been introduced.

III.SELECTION OF CONTROLLING METHOD

UPQC is vastly studied by several researches as an infinite method for power quality conditioning [4-6]. Different UPQC controlling methods can be classified in three following classes: time-domain Abbreviations and Acronyms controlling method, frequency-domain controlling method and new techniques. Furrier method is one of the methods can be named as frequency-domain methods.The methods such as P-Q theory, instantaneous reactive power, algorithms based on the synchronous d-q reference frame, instantaneous power balance method, balanced energy method, synchronous detection algorithm, direct detection algorithm and notch filter based controlling method are some can be mentioned for time-domain methods. Dead beat control, space vector modulation and wavelet conversion are some of the new techniques [7].

Three general standards considered to select the controlling method are load characteristics, required accuracy and application facility. All methods end in to similar results when the reference signal is calculated under balanced and sinusoidal conditions where each ends in to different results under unbalanced and non sinusoidal conditions. Dead beat controlling method presents the best operation among the others but more expense should be paid for its calculations.

Among the introduced methods the reference frame methods seem to be more appropriate. The fact is that it needs sinusoidal and balanced voltage and is not sensitive to voltage distortions and is relatively simple. In result, the response time of the control system shortens. So it’s prior to utilize the synchronous reference frame theory with Fuzzy logic controller in UPQC controlling circuit.

IV.DESIGN OF ACTIVE FILTERS

For UPQC two different Active filters with proper control circuits are provided those are

a. Series Active Filter (SAF) Control

b. Shunt Active Filter (PAF) Control

and one more control also provided for the enhancement of system performance.

c. DC Link voltage control

A. Series Active Filter (SAF) Control

Sinusoidal voltage controlling strategy of load is generally proposed to control the series part of UPQC. Here, the series part of UPQC is controlled in a way that it compensates the whole voltage distortions and maintains load voltage 3-phase balanced sinusoidal. In order to reach this, the synchronous reference frame theory is applied [8].

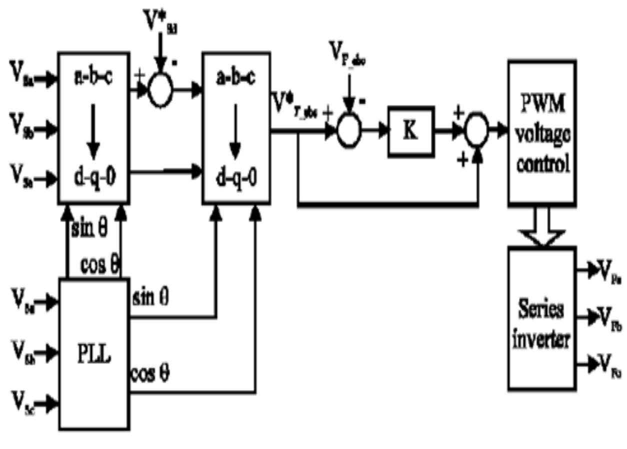

Figure 3. controlling circuit of Series Active Filter

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In this method the desired value of load phase voltage in d axis and q axis is compared with the load voltage and the result is considered as the reference signal.The controlling circuit of series active filter is shown in Figure.3. SPWM method is used to optimize the response of series inverter.

B. Shunt Active Filter (PAF) Control

The measured currents of load are transferred into dq0 frame using sinusoidal functions through dq0 synchronous reference frame conversion. The sinusoidal functions are obtained through the grid voltage using PLL. Here, the currents are divided into AC and DC components.

$$i_{id} = \bar{i}_{id} + \tilde{i}_{ld}, i_{lq} = \bar{i}_{lq} + \tilde{i}_{lq} \qquad (1)$$

The active part of current is i_d and i_q is the reactive one. AC and DC elements can be derived by a low pass filter. Controlling algorithm corrects the system's power factor and compensates the all current harmonic components by generating the reference current as

$$i^*{}_{fd} = \tilde{i}_{ld,} i^*{}_{fq} = \tilde{i}_{lq} \qquad (2)$$

Hear, system's current are:

$$i_{sd} = \bar{i}_{lq}, i_{sq} = 0 \qquad (3)$$

Switching losses and the power received from the DC link capacitors through the series inverter can decrease the average value of DC bus voltage. Other distortions such as unbalance conditions and sudden changes in load current can result in oscillations in DC bus voltage.

In order to track the error between the measured and desired capacitor voltage values, a PI and Fuzzy logic controllers are applied. The resulted controlling signal is applied to current control system in shunt voltage source inverter which stabilizes the DC capacitor voltage by receiving required power from the source. Δi_{dc}, the output of PI and Fuzzy logic controllers is added individually to the q component of reference current and so the reference current would be as Eq.4

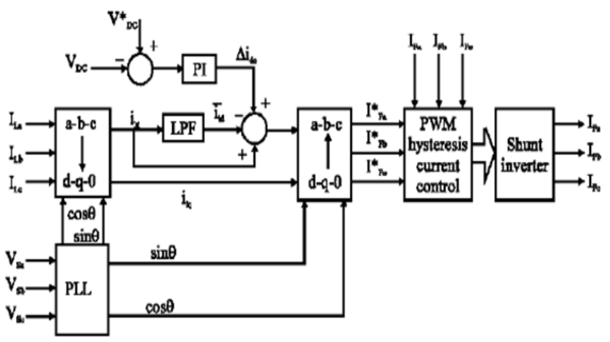

Figure 4. Controlling circuit of Shunt Active Filter

$$i^*{}_{cd} = \tilde{i}_{ld,} + \Delta i_{dc,} i_{cq} = i_{lq} \qquad (4)$$

The reference current is transferred into abc frame through reverse conversion of synchronous reference frame as shown in Figure. 4,. Resulted reference current (i^*_{fa}, i^*_{fb} and i^*_{fc}) are compared with the output current of shunt inverter (i_{fa}, i_{fb} and i_{fc}) in PWM. Now, the current controller and the required controlling pulses are generated. Required compensation current is generated by inverter applying these signals to shunt inverter's power switch gates

DC Link voltage control

A PI controller is used to track the error exists between the measured and desired values of capacitor voltage in order to control the DC link voltage as Figure 5 as mentioned in [7].

Figure 1. Block diagram of Dc link voltage control

This signal is applied to current control system in shunt voltage source inverter in a way that the DC capacitor voltage is stabilized by receiving the required active power from the grid. Correct regulation of proportional controller's parameter responding speed of control system. Integral gain of controller corrects the steady state error of the voltage control system. If this gain value is selected large, the resulted error in steady state is corrected faster and too much increase in its value ends in overshoot in system response. plays an important role in DC voltage control system's response. Too much increase in proportional gain leads to instability in control system and too much reduction decreases the responding speed of control system. Integral gain of controller corrects the steady state error of the voltage control system. If this gain value is selected large, the resulted error in steady state is corrected faster and too much increase in its value ends in overshoot in system response.

IV.Fuzzy Logic Control

A. Fuzzy logic principle

The structure of a complete fuzzy control system is composed from the following blocs: Fuzzification, Knowledgebase, Inference engine, Defuzzification. Figure 6 shows the structure of a fuzzy logic controller

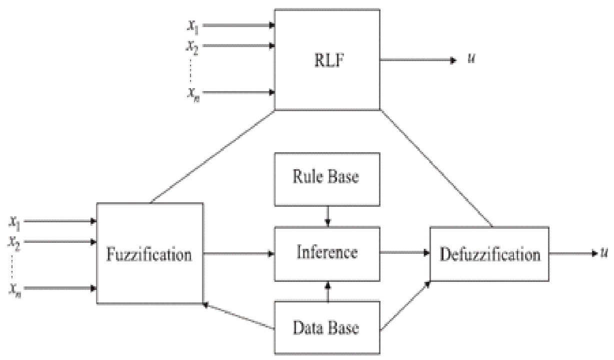

Figure 6. The structure of a fuzzy logic controller

The fuzzification module converts the crisp values of the control inputs into fuzzy values. A fuzzy variable has values which are defined by linguistic variables (fuzzy sets or subsets) such as low, Medium, high, big, slow . . .where

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each is defined by a gradually varying membership function. In fuzzy set terminology, all the possible values that a variable can assume are named universe of dis course, and the fuzzy sets (characterized by membership function) cover the whole universe of discourse. The shape fuzzy sets can be triangular, trapezoidale, etc [11, 12].

A fuzzy control essentially embeds the intuition and experience of a human operator, and sometimes those of a designer and researcher. The data base and the rules form the knowledge base which is used to obtain the inference relation R. The data base contains a description of input and output variables using fuzzy sets. The rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristics, it contains a collection of fuzzy conditional statements expressed as a set of IF-THEN rules, such as:

$R^{(i)}$: If x_1 is F_1 and x_2 is F_2 ……… x_n is Fn
THEN Y is $G^{(i)}$, i = 1……..M (5)

Where: (x_1, x_2,…….. x_n) is the input variables vector, Yis the control variable, M is the number of rules, n is the number fuzzy variables, (F1, F2, . . .Fn) are the fuzzy sets.

For the given rule base of a control system, the fuzzy controller determines the rule base to be fired for the specific input signal condition and then computes the effective control action (the output fuzzy variable) [11, 13]. The composition operation is the method by which such a control output can be generated using the rule base. Several composition methods, such as max-min or sup-min and max-dot have been proposed in the literature.

The mathematical procedure of converting fuzzy values into crisp values is known as 'defuzzification'. A number of defuzzification methods have been suggested. The choice of defuzzification methods usually depends on the application and the available processing power. This operation can be performed by several methods of which center of gravity (or centroid) and height methods are common [13, 14].

B. Fuzzy logic controller

The general structure of a complete fuzzy control system is given in Figure. 7. The plant control 'u' is inferred from the two state variables, error (e) and change in error (Äe) [15].

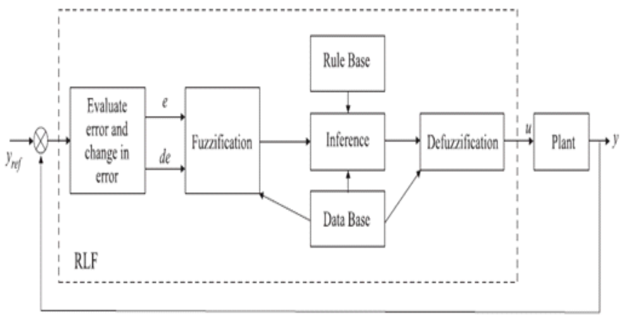

Figure 7. Basic structure of fuzzy control system

The actual crisp input are approximates to the closer values of the respective universes of is course. Hence, the fuzzyfied inputs are described by singleton fuzzy sets. The elaboration of this controller is based on the phase plan. The control rules are designed to assign a fuzzy set of the control input u for each combination of fuzzy sets of e and _e [19, 20].Here NB is negative big, NM is negative medium, ZR is zero, PM is positive medium and PB is positive big, are labels of fuzzy sets and their corresponding membership functions are depicted in Figures. 8, 9 and 10, respectively.Table 1 shows one of possible control rule base. The rows represent the rate of the error change eÿ and the columns represent the error e. Each pair (e, eÿ) determines the output level NB to PB corresponding to u.

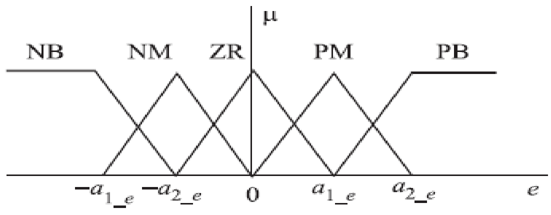

Figure 8. Membership functions for input I

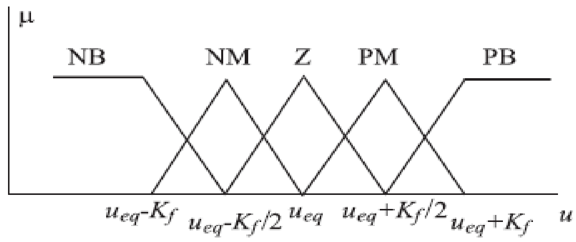

Figure 9 Membership functions for input Äi

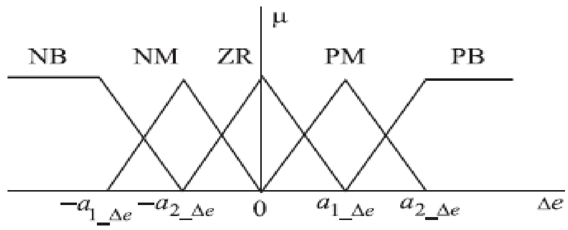

Figure 10. Membership functions for output u

The continuity of input membership functions, reasoning method, and defuzzification method for the continuity of the mapping u_{fuzzy}(e, eÿ) is necessary. In this paper, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [15, 18].

TABLE I. RULES BASE FOR CURRENT CONTROL

Du		Δi				
		NB	NM	ZR	PM	PB
i	NB	NB	NB	NM	NM	ZR
	NM	NB	NM	NM	ZR	PM
	ZR	NM	NM	ZR	PM	PM
	PM	NM	ZR	PM	PM	GP
	PB	ZR	PM	PM	GP	GP

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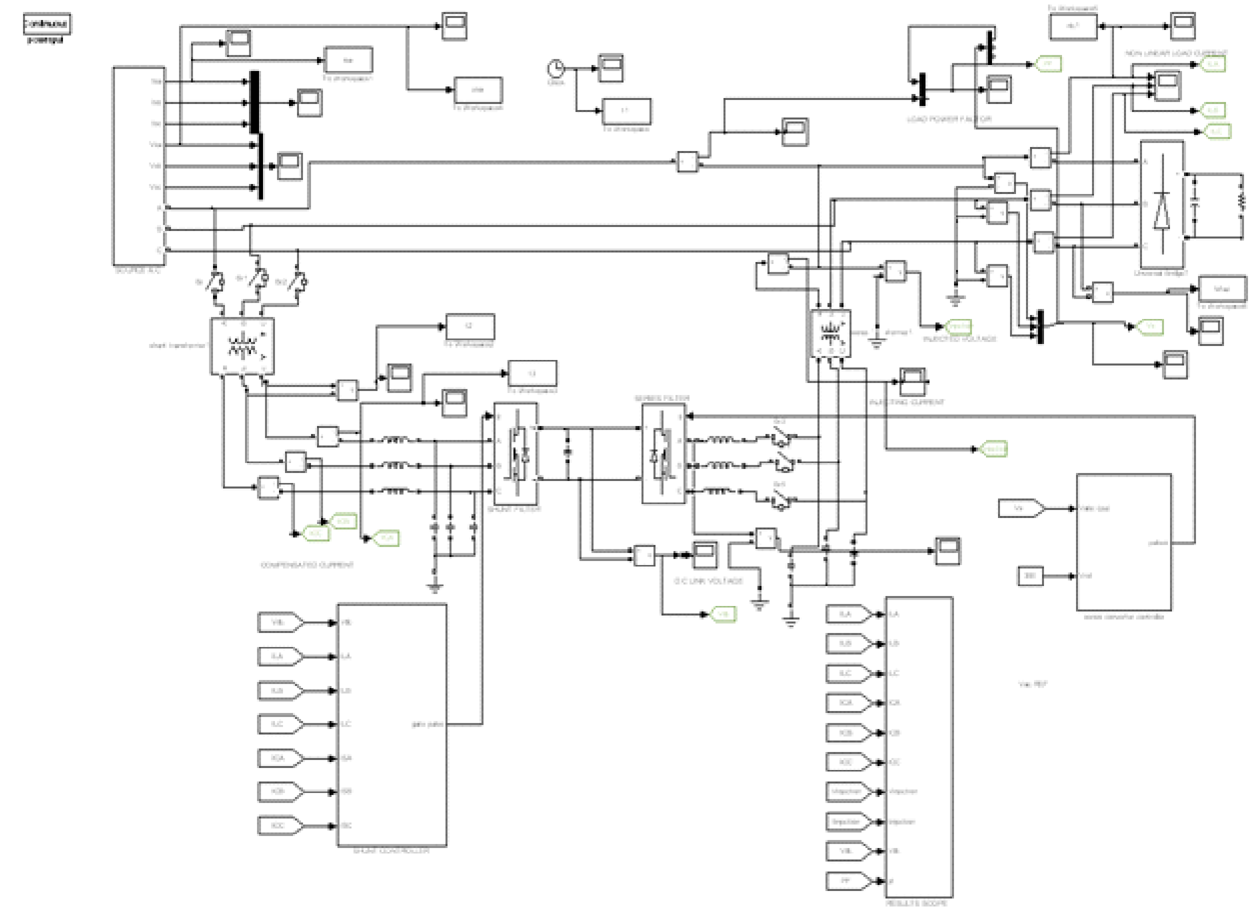

Figure 11. MATLAB / Simulink diagram of UPQC

V. Simulation and Results

In order to validate the control strategies as discussed above, digital simulation studies were made the system described in Figure. 2. The voltage and currents loops of the system were also designed and simulated respectively with fuzzy control and PI control. The feedback control algorithms were iterated until best simulation results were obtained. The simulation is realized using the SIMULINK software in MATLAB environment simulated circuit is given in figure.11.

The control presents the best performances, to achieve tracking of the desired trajectory. The fuzzy controller rejects the load disturbance rapidly with no overshoot and with a negligible steady state error. The current is limited in its maximal admissible value by a saturation function. The reason for superior performance of fuzzy controlled system is that basically it is adaptive in nature and the controller is able to realize different control law for each input state (Error and Change in Error). In this study, power circuit is modeled as a 3-phase 3-wire system with a non linear load comprised of RC load which is connected to grid through 3-phase diode bridge. Circuit parameters used in simulation are shown in Table 1. The simulated load is a parallel RC and diode rectifier bridge nonlinear 3-phase load which imposes a non sinusoidal current to source. Non-linear Load current is shown in Figure 12.

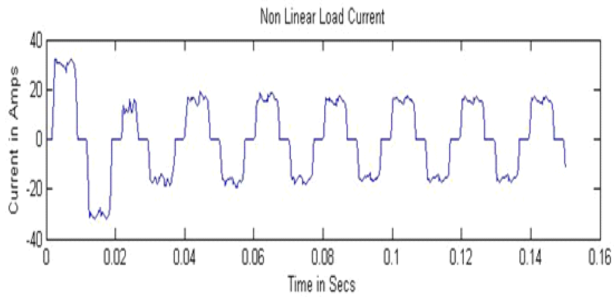

Figure 12. Non-linear Load current

In Figure. 13 the source current, injected current compensated current before and after being compensated by shunt inverter are shown. Shunt inverter is activated in 0.02 sec of operation. Immediately, the source current is corrected. The results shown in Figure. 13 present that the shunt part has been able to correct the source current appropriately.

Figure.14 shows the source side voltage, load side voltage and the voltage injected by the series inverter to simulate swell and sag of the voltage. As shown in Figure. 14 the voltage distortions imposed to load from the source are properly compensated by series inverter. In this simulation, series inverter operates at 0.02 sec and voltage source faces with 100 V voltage sag. A voltage swell with 50 V voltage peak occurs in 0.08 sec. Simulation results show that the load voltage is constant during the operation of UPQC series inverter.

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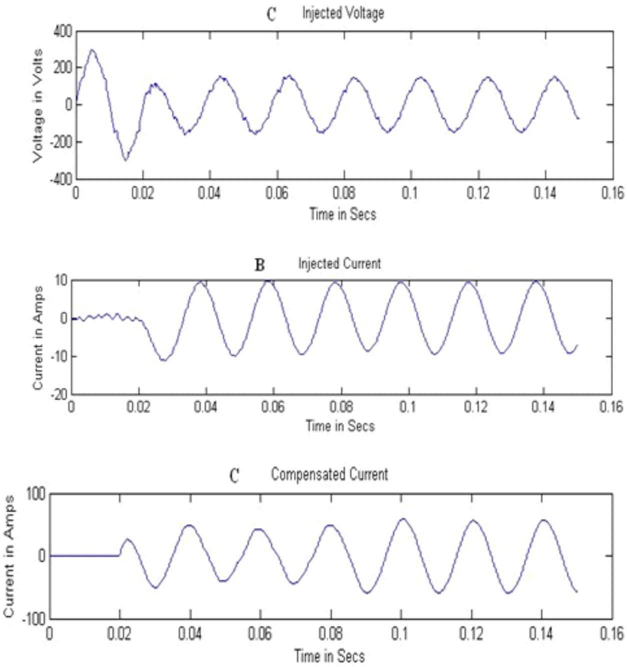

Figure 13. Source current (A), Injected current (B)and compensated current(C).

By using PI and Fuzzy logic Controllers individually for shunt controller DC link voltage is shown in Figure. 15. From that the distortions in DC link voltage can be minimized by Fuzzy logic controller In this simulation, series and shunt inverters start to operate at 0.02 sec. As it is seen, capacitor voltage is decreasing until this moment. By operating shunt inverter, the capacitor voltage increases and reaches to the reference value (600 V). At 0.04 sec of operation voltage sag with 100 V amplitude occurs in source voltage.

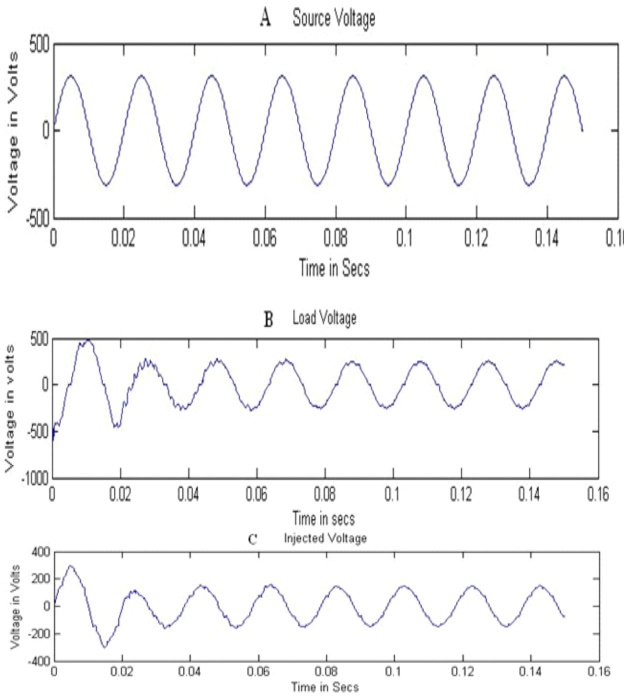

Figure 14. source side voltage (A),load side voltage (B) and the voltage injected (C)

The average value of capacitor voltage drops about 10 V occurring this voltage sag and faces with small oscillations in lower values. At 0.08 sec of operation voltage swell with about 50 Vamplitude occurs at 0.08 sec of operation. The average value of capacitor increases about 15 V occurring this swell and faces with small oscillations in voltages around 600 V. Figure 15 shows the exact operation of control loop of DC link capacitor voltage from fuzzy logic controller settling time (0.04 s) is less than PI controller(0.058s). RL load with 6 kW active power and 6 kVAR reactive power is applied in simulation to study how reactive power is compensated by shunt inverter. Simulation results show that the phase difference between voltage and current is cleared by shunt inverter operation. Actually, by operating UPQC, required reactive power is provided via., UPQC.

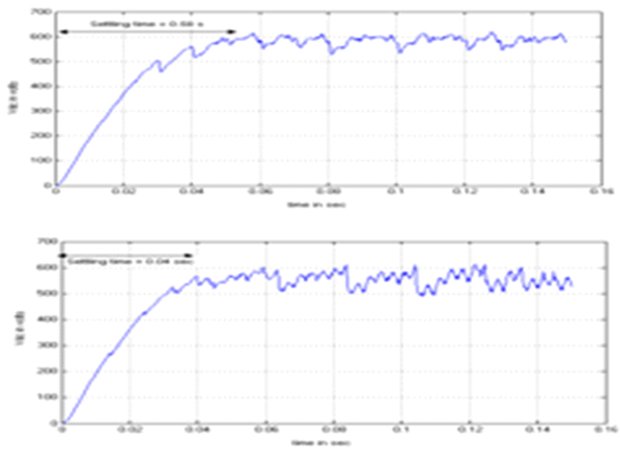

Figure 15. DC link voltage by PI and Fuzzy logic Controller

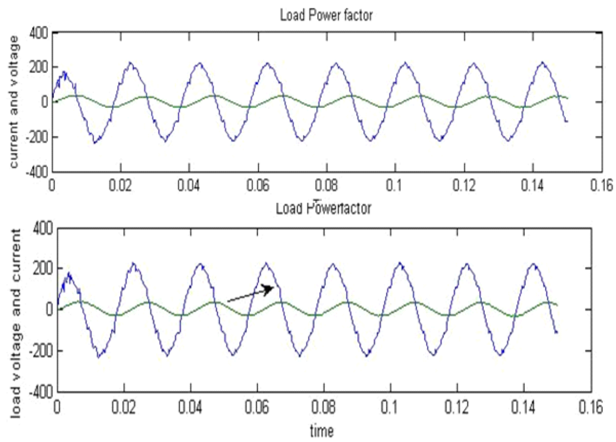

Figure16. Load Power factor by PI and Fuzzy logic controller

16 shows the load current and voltage with PI and Fuzzy logic controller for simulink circuit simulated individually. As it is shown, load current phase leads voltage phase initially. At 0.06 sec of operation and operating shunt inverter the phase difference between voltage and current gets zero.

Comparison of this study results with related studies, indicates that the proposed system compensates voltage and current distortions accurately and the response time of the control system is relatively low and also the proposed control system is simply applicable.

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TABLE II. SIMULINK PARAMETERS

Parameters	Values
Source Phase voltage	220v/50Hz
DC Link Voltage	600v
Shunt inverter rating	15kVA
Series inverter rating	15kVA
Shunt inverter inductance(L_f)	3mH
Shunt inverter Capacitance (C_f)	10μF
Switching Frequency	20kHz
Series inverter inductance(L_s)	3mH
Series inverter Capacitance (Cs)	15μF
Series inverter Resistance (R_s)	12Ω

VI. CONCLUSIONS

In this proposed Unified Power Quality Conditioner (UPQC) is designed and simulated through synchronous reference frame theory with PI and Fuzzy logic controller. Simulation results show the proposed system's ability in voltage distortion, reactive power and current harmonics compensation. Fuzzy logic controller balances the power between series and shunt inverters by stabilizing DC link voltage in faster response as compare with PI controller.

The operation of proposed system is analyzed using MATLAB/SIMULINK software. Simulation results confirm the correct operation of the proposed system.

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